Renewable and Sustainable Energy Reviews 16 (2012) 4422–4431

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Renewable energy use in Lebanon: Barriers and solutions

E. Kinab [a], M. Elkhoury [b,*]

[a] *Department of Mechanical Engineering, American University of Beirut, P.O. Box 11-0236, Beirut, Lebanon*
[b] *Department of Industrial and Mechanical Engineering, Lebanese American University, P.O. Box 36 Byblos, Lebanon*

ARTICLE INFO

Article history:
Received 26 January 2012
Received in revised form
10 April 2012
Accepted 18 April 2012
Available online 21 June 2012

Keywords:
Biomass
Geothermal energy
Renewable energy
Solar energy
Wind energy

ABSTRACT

The ability to discover and utilize a reliable source of renewable energy is vital in order to reduce the effects of global warming and to decrease and/or eliminate reliance on fossil fuel. Recently, countries around the world have been recognizing the immediate need to tackle the current energy problems. While the developed countries have been investing in renewable energy for the past two decades, developing nations now realize the importance of adopting such energy sourcing strategies [1]. It has long been understood and it is very well-known that energy is the driving force behind economic and social development of a state and its population. The following paper presents an overview of the current renewable energy status in Lebanon. It focuses on barriers hindering improvements and proposes pertinent solutions.

Contents

1. Introduction

Developing countries are in a race against time. Satisfying the need of their expanding/growing population and economical activities requires developing modern and sustainable forms of energy. Different studies describing methodologies and techniques were introduced in the developing countries for power systems expansion, planning, and restructuring. Avetisyan et al. [2] proposed a mathematical model relating between the technical and economic criteria for the optimal expansion of a developing power system under the conditions of market economy and environmental constraints. Al-Shaalan [3] presented the most prominent challenges and problems in power system planning in

* Corresponding author.
E-mail addresses: elias.kinab@aub.edu.lb (E. Kinab), mkhoury@lau.edu.lb (M. Elkhoury).

1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2012.04.030

developing countries that influence the decision making process. Economists agree that issues such as fuel shortage and price fluctuations have no impact on renewable energy [1], and that in turn reinforce the variety and protection of supply.

Based on a study conducted by the United Nations in 2009, the lack of energy supply that will be soon facing the third world countries is mainly due to the following four factors:

1. Population growth (exponential growth).
2. Load growth (exponential growth).
3. Stable governments and political situation planning.
4. Tangible resources (Natural, human, etc.).

In the twentieth century there was a "twentyfold increase" in the use of fossil fuel. Between 1980 and 2009, the worldwide annual growth rate was 2%. Based on the US Energy Information Administration's 2011 estimate, the estimated of 471.8 EJ (1 ExaJoules $=10^{18}$ J) total consumption with "fossil fuels supplying 87% of the world's energy" [4].

According to the Statistical Review of World Energy report of 2011 [3], 16% of the world energy consumption came from renewable energy sources in 2011, 83% of which originates from biomass [5]. What makes these sources attractive is their ability to produce energy with or without negligible emissions, insuring minimal environmental impact. In addition, they will not run out like other conventional sources of energy that mainly rely on fossil fuels. The growth in renewable energy use in the world is the result of countless renewable energy policies in numerous countries in response to the depletion of fossil fuels, which is the principal source of energy in the world, not to mention the environmental impact of high CO_2 emissions and their consequences from global warming to green-house effect. With the increase in global awareness and consciousness, the promotion of renewable energies has become common in the world, resulting in policy development for renewable energy in around 119 countries by early 2011 [5], as illustrated in Fig. 1. In the EU, many policies and strategies were adopted. The European parliament, the Spring European Council, and the European Commission have set new rules for gas supply which regulate its consumption and in consequence limit the emissions in one hand and push the investors to invest more in renewable energy sources. As a result, the annual investment in renewable energy has increased to reach $211 billion in 2011 [5]. However, the world is still far from the targets set in 2002 at the World Summit on Sustainable Development (WSSD) at which many countries agreed on increasing the share of "renewable in the global energy mix".

Middle Eastern countries provide significant amounts of energy supply to the world, especially the energy derived from petroleum. In the past couple of decades, the oil-rich countries have shown an increased interest in investing in renewable energy sources, mainly in the gulf region [6–8] where the need for desalinated water by the high energy consumers has increased. Furthermore, other countries in the Middle East and North Africa MENA region with abundant solar potential have adopted solar renewable energy plans and projects [9,10] that were supported by studies done by European countries [11,12]. Currently, each country is developing a road map for the implementation of renewable energy by founding research and development centers [13], identifying renewable energy sources [14], exploring potentials in solar [15,16] and wind energies [17–19]. Other countries in the Middle East do not have any natural resources and thus heavily rely on imported petroleum product and coal. Lebanon for instance imports 98% of its energy requirements [4]. The need to invest in Renewable Energy Technology (RET) in countries such as Lebanon is critical for its economic and social prosperity. In this context, the following paper addresses the current energy condition in Lebanon, explains barriers and presents alternatives in the form of renewable energy sources.

2. Geographical, economical and energy status of Lebanon

Lebanon is nearly rectangular in shape with an area of 10,452 km^2 that stretches from north to south along the eastern side of the Mediterranean Sea (Beirut: latitude 33°49′N and longitude 35°29′E). The length of Lebanon is more or less four times its width; it becomes increasingly narrow as we move from the north to the south. The country is bordered by Syria in the north, the east, and the south east, and by Israel and the Mediterranean Sea in the south and the west, respectively. The length of Lebanon is nearly 220 km with an approximate average width of 56 km. Lebanon is a mountainous country and is fundamentally divided into four main divisions that run in general from the north to the south, the Lebanese coast, the western Mount Lebanon, the Beqaa valley and the eastern Mount Lebanon [20]. The swinging between lowland and highland along with the complex geography of Lebanon has a major impact on its climate, soils, land forms and vegetation, that differ within short distances. With its Mediterranean climate, depicted in Fig. 2, the Lebanese summer is long, hot and dry while the winter is rainy and cold. In the mountain the climate is a tad different; summer is moderate and humid while winter is cold and snow covers many of its summits. The average annual temperature is 20.2 °C and varies between 14 °C and 27 °C in January and July, respectively [21].

The economy in Lebanon, along with its markets, is considered as a developing economy. The public sector contributes to around 25% of the total demand, while the private sector covers the remaining 75% of the total demand. Lebanon is also known by its large and effective banking sector that plays a major role in the growth and recovery. In 1975 the civil war damaged Lebanon's

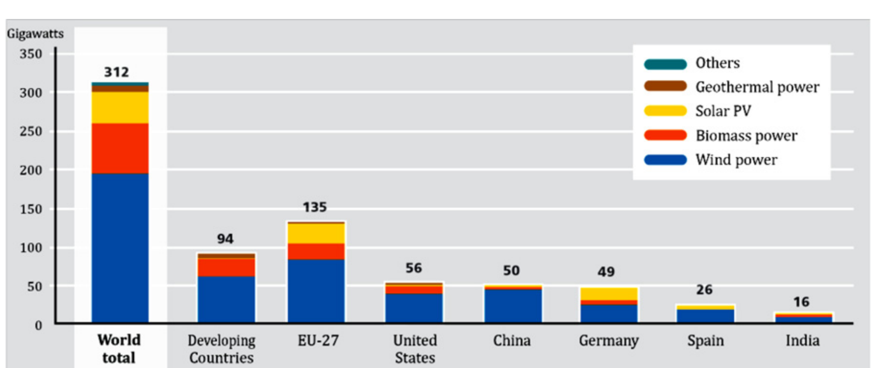

Fig. 1. Renewable power capacities, developing world, EU and top five countries [5].

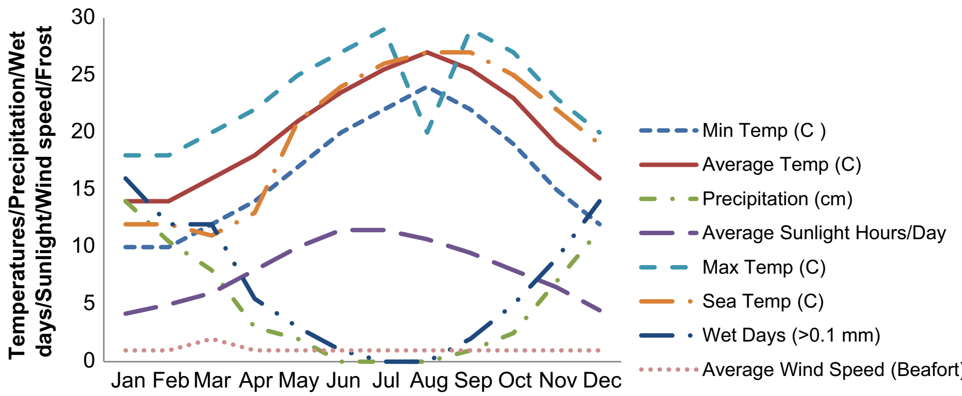

Fig. 2. Beirut, Lebanon climate graph (altitude: 29 m) [21].

economy and infrastructure and destroyed its position as the Middle East's bank and warehouse. However, Lebanon knew a great economic recovery at the beginning of the 1990s where the current GDP per capita has expanded 353% [22] as a result of the end of the war. The Lebanese GPD has risen steadily since 1990 excluding years (1996, 2006 and 2007), in 2008 the increase was 8.5%, in 2009 it went up to 9%, and down to 7% in 2010 [23].

Lebanon does not produce any of the conventional energy sources such as oil or coal despite the studies that conclude a high possibility of finding oil in its land and regional water. The energy produced and consumed in Lebanon is mainly imported, in addition to some renewable sources that do not cover more than 2% of the entire energy consumption [24]. The industrial sector uses around 25% of Lebanon's energy consumption, while 30% is used for the residential, public and commercial sector and the remaining 45% is used in the transportation sector [24]. Electricité du Liban (EDL) company is responsible for the production, transportation, and distribution of electricity in Lebanon. EDL produces electricity in around seven thermal factories (nominal installed capacity 2038 MW—actual generation capacity 1685 MW) [25] and some hydraulic energy in different locations in the country (nominal installed capacity 274 MW—actual generation capacity 190 MW) [25], the evolution of which is presented in Fig. 3. The company suffers from a yearly shortage of 34% in the produced energy, 14% of which is technically related, whereas the rest 20% of the loss is nontechnical such us bill non-payment and power theft [24]. In order to cover this shortage the government buys electricity from Syria (589 GWh) and Egypt (527 GWh) [25] and relies on small firms in some villages that produce and sell electricity to their citizens. Despite all the positive geographical and climatic positive conditions such as the number of sunshine hours and the solar flow, Lebanon does not benefit from the renewable energy sources even if has a great shortage in its production and that is mainly due to the absence of clear policies from the government to promote the use of these energy sources, the overall mentality and culture of the people, and the high cost of establishing these sources in comparison to the low price of the electricity [24].

3. Overall policy related to energy in Lebanon

The Ministry of Energy and Water is the one responsible for the petroleum and gas sector in addition to the electricity production through the EDL Company which has a monopoly on the electricity production in the country. The Ministry is also responsible for the pollution control in the petroleum industry and is in charge of the energy policy in Lebanon. The government had, until the year 1988, monopoly over the petroleum and gas

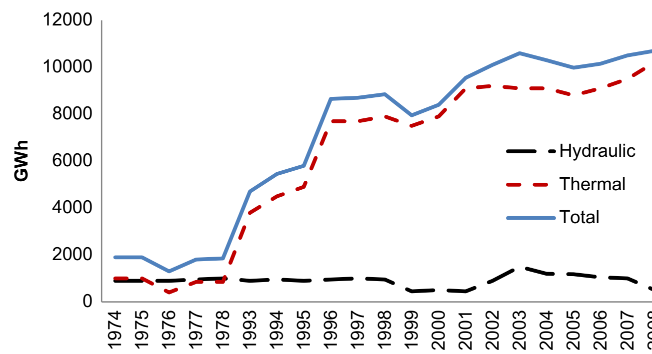

Fig. 3. Evolution of electricity production.

sector which is now controlled by the private sector, and where the government has limited interference and particularly to control prices. The lack of any global, modern and clear policy in the energy sector has to do with the laws in the country that date back to the 1970s and the absence of any trained civil servants result in a lag in policy definition [26].

4. Current economic state of energy in Lebanon

The actual tariffs adopted as the sale price of electric energy are fixed by EDL Company and approved by the Ministry of Energy and Water and the ministry of Finance. The present tariffs are classified by sectors: residential, commercial, industrial, public lighting, etc. For example, the residential tariff is composed of two charges; the first fixed monthly charges are imposed as a function of the capacity, whereas the second charges are based on consumption trenches starting with 35 Lebanese pounds (LBP) (0.02$) per kWh for the first 100 kWh per month and increases to 200 Lebanese pounds (LBP) (0.13$) per kWh when consumption exceeds 500 kWh per month [36]. The industrial tariff is composed of three daily tariffs for active consumption (kWh) and one tariff for reactive consumption (kVAr) [36]. The average cost of electricity in 2009 was 255 Lebanese Pounds (LBP) (0.17$) per kWh, out of which 75% (0.10$) is fuel bill [25]. Effectively, the contribution of the fuel bill to the total cost was around 1450 M$ (75%) and 1165 M$ (62%) in 2008 and 2009, respectively. This in turn was due to fluctuations in the cost of fuel and was highly subsidized by the government.

These presented tariffs do not reflect the marginal production cost (0.21 $/kWh) [27] and has been the same since the nineties despite the increase in the overall costs. The main reason, according to the Ministry of Energy and Water, lies in the inability

of EDL to restructure the tariffs unless the electricity is supplied 24 h/day. Thus it is facing a relatively high electric load shortage (5–40%) leading to regular daily outage programs and unscheduled outage. Therefore, EDL has been facing a financial deficit that averaged $1.5 billion for the past three years, according to the ministry of Energy and Water [25]. For instance, the subsidy from 1992 to 2009 was $6.4 billion and the total investment for that period was only $1.6 billion ($50 million from 2002 to 2008) resulting in a total deficit of about $8 billion without interest. In addition, EDL losses affect directly the national economy. As estimated by Electricite De France (EDF) and the World Bank in the Public Expenditure Review (PER) [25], the cost of outsourced electricity varies between 200 and 2000 $/MWh. In 2009 the losses of the Lebanese economy averaged at a value of $700 per MWh (including the cost of buying electricity from private generators), summing up to $2.5 billion that was divided between $1.3 billion for private generation and $1.2 billion for direct consumer losses. As a result, the energy sector in Lebanon is causing the government an annual deficit of 1.5 billion dollars, while the losses on the national economy are estimated at not less than $2.5 billion dollars per year. This is mainly due to high fuel prices, bad operating status of the old inefficient existing power plants, transmission and distribution losses, wrong tariff structure, and lack of investments.

A durable solution for this economic crisis could be assured by investing in this sector, specifically in the generation, transmission and distribution components. The target is to provide about 4870 M$ to meet the estimated demand of 4000 MW in 2015 with 24/24 h of service [25]. Renewable energy technologies could contribute to this new generation capacity. However, their cost is relatively high in comparison to conventional power plants. Effectively, generation utilizing hydraulic power plants cost as high as 5800 $/kW and about 1950 $/kW when wind power systems are employed. Generation cost from waste to energy systems could be estimated at about 1900 $/kW, while it may well be about 1000 $/kW for the conventional power plants.

5. Environmental requirements for the renewable energy sources development

Greenhouse gas (GHG) emissions in Lebanon are mainly due to transportation, electricity generation, manufacturing industries, and energy consumption in the residential, commercial and institutional sub-sectors, etc. As mentioned before, 98% of the energy produced in Lebanon is mainly derived from using the imported petroleum products and coal [26], in addition to the 2% that is produced from the hydroelectric plants available in the country, and some biomass products such as wood and charcoal. Being one of many developing countries, the generation of energy in Lebanon is inefficient; this would lead to many environmental impacts. The main loss is represented in the electricity production process where most thermal plants used for this purpose are operating at low efficiency, in addition to distribution and transmission loss since their networks need important rehabilitation and improvements. For instance, the total electric loss amounts to 55% (15% of the electricity produced in 1997 is technical and 40% is non-technical [26]). This loss is considerably higher than many developed and developing countries. The Lebanese governments through the past 20 years showed some concern regarding the pollution and the increased GHG emissions. However, no attempt was made to save on energy bills, which without doubt led to higher emissions. As a result, Lebanon was ranked 84 in the year 2005 in CO_2 emissions among all world countries, with a 4.4 tones only other numbers in Tables 1–5 of CO_2 emissions in 2005 [28].

Many mitigation plans were proposed by scholars through several studies conducted for this purpose [28,29], which assessed

Table 2
Summary of CO_2 emissions (Gg) by fuel source [28].

Fuel type	Consumption (TJ)	CO_2 (Gg)
Gasoline	55,694.55	3821.03
Jet kerosine	85.166	6.0285
Kerosene	4.475	0.318
Gas/diesel oil	35,449.23	2599.35
Fuel oil	567,708.65	4343.48
LPG	6907.26	431.261
Lubricants	12.053	0.437
Coking coal	5040	467.248
Municipal solid wastes	64.995	4.765
Charcoal	46.64	5.363
Wood (solid biomass)	2400	550.096
International bunkers	6420.96	454.507

Table 3
Summary of CO_2 emissions (Gg) by fuel type [28].

Fuel type	Consumption (TJ)	CO_2 (Gg)
Total liquid fuel (including LPG)	15,492,636	11,206.68
Total solid fuel	5040	467.248
Total biomass	2446.64	263.221

Table 4
Summary of CO_2 emissions (Gg) by energy use by sector [28].

Sector	CO_2 (Gg)
Energy industries	3615.05
Manufacturing industries and construction	2774.09
Transport	3957.12
Commercial/institutional	226.319
Residential	534.25
Agriculture/forestry/fishing	571.857
International bunkers	454

Table 1
Summary table of the contribution of each sector in the gas emissions in Lebanon [28].

Sector	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)	NO_x (Gg)	CO (Gg)	NMV0C (Gg)	CO_2 (Gg)
Energy	11,678.694	1.3794	0.1157	54.0959	473.7119	87.3411	79.6036
Industry	1924.063	NO	NO	0.01112	0.0003	273.888	3.382
Solvents	NE	NE	NE	NE	NE	NE	NE
Agriculture		7.97862	3.0147	0.00146	0.04306		
Land-use change and forestry	200.4132	0.253	0.00168	0.06276	2.213		
Waste	0	42.804	0	0	0	0	0
Total	13,803.17702	52.41502	3.13208	54.17124	475.9682 6	361.2291	82.9852

Table 5
Summary of non-CO_2 emissions (Gg) by energy use of sectors [28].

Sector	CH_4	N_2O	NO_x	CO	NMV0C	SO_2
Energy industries	0.1418	0.0283	9.4584	0.77093	0.2364	45.021
Manufacturing industries and construction	0.11545	0.02517	7.6684	1.0862	0.2559	24.667
Transport						2.679
Road	1.1221	0.0344	34.824	447.193	83.87708	
Domestic aviation	4.2583×10^{-5}	0.000177	0.0255	0.00856	0.00425	
Domestic navigation	9.11×10^{-5}	1.094×10^{-5}	0.0273	0.01822	0.00364	
Commercial/institutional	0.0284	0.001568	0.2844	0.08447	0.01594	1.13
Residential	1.499	0.0214	1.0281	24.564	2.9153	2.579
Agriculture/forestry/fishing	0.0779	0.00467	0.7798	0.1559	0.0389	3.528
Total	2.9847	0.1157	54.0959	473.7119	87.3411	79.6036
International bunkers	0.0032105	0.0128419	1.926288	0.642096	0.321048	0.14134

Table 6
Hydro-electric production by location (MWh) [31].

Location	2000	2001	2002	2003	2004	2005	2006	2007	2008
Safa	17	11	26	37	25	22	25	18	13
Litani	257	146	424	1027	846	775	457	384	208
Naher Ibrahim	75	72	94	121	197	105	84	79	65
Bared	43	44	60	85	62	62	52	39	33
Kadisha	58	59	74	92	81	82	77	65	54
Total	450	332	678	1362	1211	1046	695	585	373

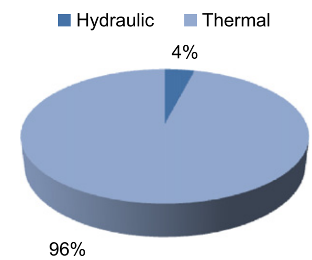

Fig. 4. Electricity production level in 2008 (hydraulic and thermal) [23].

improvement scenarios relating to the transportation system, manufacturing industries, and the construction sub-contractors. These scenarios [30,31] addressed the possibility of relying on several different conventional methods [8–12], proposed mitigation scenarios relaying on renewable energy sources for the first time, and showed clearly how such energy sources would have a great impact on the environment once they are applied in Lebanon, especially when their capital prices become competitor in the market [29]. Therefore, the utilization of renewable energy sources would have a great impact on the environment as commonly known, since they represent clean means of energy production with negligible or zero emissions.

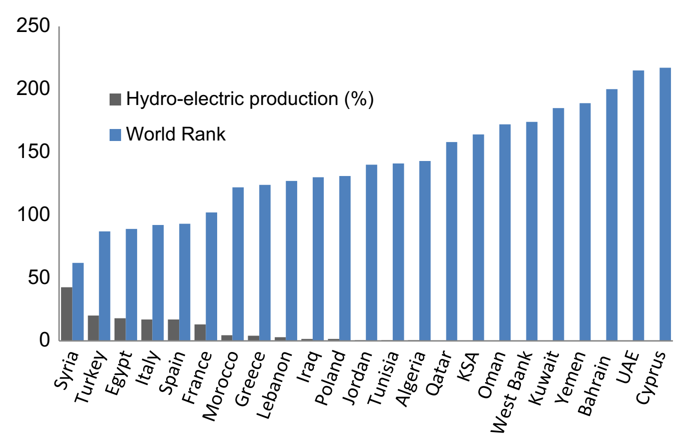

Fig. 5. Hydro-electric production (%) and world rank [22].

6. Renewable energy use in Lebanon

6.1. Hydro

The main source of renewable electricity generation in Lebanon is hydropower. As stated previously, Lebanon is a mountainous country, thus it has a remarkable potential in producing both Large and Small Hydro. Lebanon has a total of five hydro-electric power plants distributed on its lands from north to south, particularly in the Western Mount Lebanon. Litani power plant is the major plant located at the Litani River in the south of Lebanon. Litani river is the longest river in the country; it rises in the Beqaa valley and empties in the Mediterranean Sea in Saida, providing an annual flow of approximately 920 million cubic meter and designating it as a good source of hydro-electric energy. In 1959, the Litani River Dam was constructed by the government in order to produce electricity and water for irrigation for around 310 km^2 in the south, and 80 km^2 in the Beqaa valley. The other plants are smaller than the Litani plant and are also built as a result of some government projects and plans. However, since the sixties, no hydro-electric power plant has been implemented due to the lack of a clear strategy for this important sector. The five separate locations are listed in Table 6 along with the amount of electricity produced in each plant for the years of 2000 through 2008. It is obvious that this production is not stable, the maximum production was in the year 2003 in which a total of 1362 MWh was produced, and a minimum of 373 MWh produced in 2008. This instability in production is mainly due to the irregularity in annual rainfall especially that in recent years the average rainfall was far below the general average. This in turn affects not only the production of electricity due to falling level of rivers but also the water quantity needed for irrigation purposes [5,31]. The electricity produced in 2008 from hydro-electric stations was about 4% of the total electric power (Fig. 4). Lebanon is ranked as the 127th country in terms of the total electric production with 2.8% of its power generated by hydro-electric stations. A comparison among various countries is presented in Fig. 5.

Hydro power plants produce clean energy without fuel consumption and CO_2 emissions; they are characterized by their high efficiency and low operation and maintenance costs, their reliability, quick availability and by the long life cycle of their generating units (50 years). On the other hand, hydro power plants need huge investment for the construction phase and may disrupt the natural environment. In addition, the irregular rain and snowfall can affect the production.

Table 7
Yearly average wind speed [33].

Station	m/s
Airport	4.5
Arz	3.7
Ryak	3.9
Ksara	4.3
Khaldeh	2.8
Marjaayoun	4.5
Qlaiaat	4.4
Tripoli	3.9
Daher el Baydar	4.3

6.2. Wind energy

There is no serious wind energy production in Lebanon. Some standalone wind turbines can be seen in a few places and usually are for personal use for home electricity generation or in small private companies such as the solitary wind pumps that feed water into the salt marshes in Enfeh. However, a grid-connected wind farm is absent in Lebanon [32].

With the yearly average wind speeds acquired at key locations (Table 7), it is very obvious that the wind energy production is very limited in Lebanon with the exception of some locations. A study by Elkhoury et al. [33] revealed limited wind energy potential in Zahle that could be utilized to supplement the grid in peak hours. Recently the United Nations Development Program (UNDP) contracted a third party that carried out a mesoscale and microscale modeling for the entire country and produced a wind map with a resolution of 100 m. However, a significant uncertainty arising from low resolution of recorded monthly data and low height measurements, led to large extrapolation distances. Despite all these efforts, clear policies set by the government for wind energy investors are still absent.

6.3. Solar

Lebanon is considered to be a rich country in solar radiation which is estimated to be 3000 h at an annual average irradiance of 5.01 kWh/m^2/day.

Solar energy is collected in Lebanon utilizing thermal and photovoltaic (PV) panels. Despite the irradiance depicted in Fig. 6, the application of solar energy is still minimal which may be due to the monopoly of EDL and the low price of electricity production. Thus solar PV in its present status is not economically feasible, especially that all villages are connected to the electric grid, rendering it less desirable when compared to existing oil-based method for electricity production. However, thermal solar energy is mainly used for sanitary water heating and in resorts where it is used to warm up water in swimming pools.

6.3.1. Solar thermal energy

Due to the vast availability of solar radiation, Lebanon is greatly benefiting from the use of solar water heating. The acceptance of this type of energy is mainly due to direct saving and simplicity of use. Despite these facts and the extreme importance of solar energy, Lebanon still does not have any institutional or regulatory frame to manage this sector. Investors primarily administer this sector and abide by the laws and the rules of the market [35]. An estimate breakdown of the hot water consumption is given in Table 8.

Solar thermal energy sector investment projects and programs are supported by nongovernmental organizations (NGOs) and donations from friendly countries including, China, Spain, Turkey, Sweden and Greece.

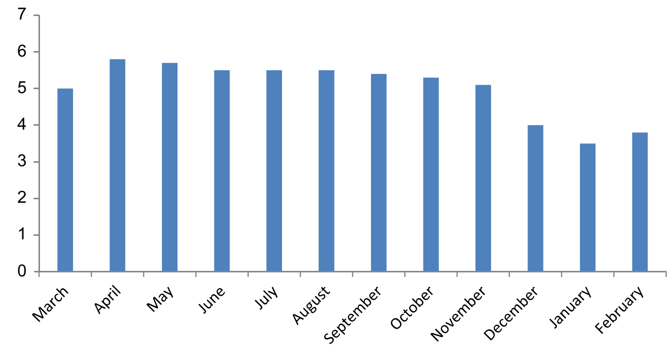

Fig. 6. Monthly averaged irradiance (kWh/m^2/day) for 2010–2011 [34].

Table 8
Estimation of domestic hot water consumption in Lebanon [36].

Sector	Sites	Number of units	Total consumption (m^3/day)
Residential	Individual houses and apartments	900,000	108,000
Commercial	Hospitals	200	478
	Hotels	322	1140
	Schools/Universities	1300	220

Therefore, the majority of the solar thermal applications in Lebanon are residential individual systems which are estimated to occupy about 61% of all the solar thermal systems installed in the market. The collective solar thermal systems for residential buildings represent about 24% of the total solar thermal applications. Large solar systems for commercial and industrial use share about 10% with 4% for retails and 1% for industrial applications. A solar thermal breakdown is shown in Fig 7 [37]. The latest large solar thermal units installed under CEDRO's commercial/institutional solar hot water applications are listed in Table 9. These systems produced about 133,000 kWh per year, saving 19,000 l of diesel fuel [34].

A graphical representation of a monthly averaged thermal solar energy produced by a large solar water heater is shown in Fig. 8. Table 10 shows the evolution of solar water heater use in Lebanon that went up from 250,000 m^2 in 2005 to about 700,000 m^2 in 2010 along the increase in energy use from 125,000 MWh in 2005 to 350,000 MWh in 2010. This clearly reflects the maturity of this sector though it is still relatively virgin and is open to many improvements [35]. Currently, the cost of the system is estimated to have a payback period of 3–5 years

6.3.2. Photovoltaic solar energy

Photovoltaic electricity generation is still a new and expensive technology. The total installed capacity till 2011 is about 85 kW with a potential of about 30 kW planned to be installed in the near future [34]. One of the PV largest installations (about 15 kW) was set up in 2008 at the Monastery of Saints Sarkis and Backos under the RAMseS (Renewable Energy Agriculture Multi-purpose System for Farmers) project supported by the European Commission's Framework 6th Program [9]. The main use of photovoltaic system arises when the national electricity grid does not reach rural areas. Although this is not the case with Lebanese villages, municipalities supported by NGOs utilized this approach for street lighting purposes. Therefore, the high initial cost of PV

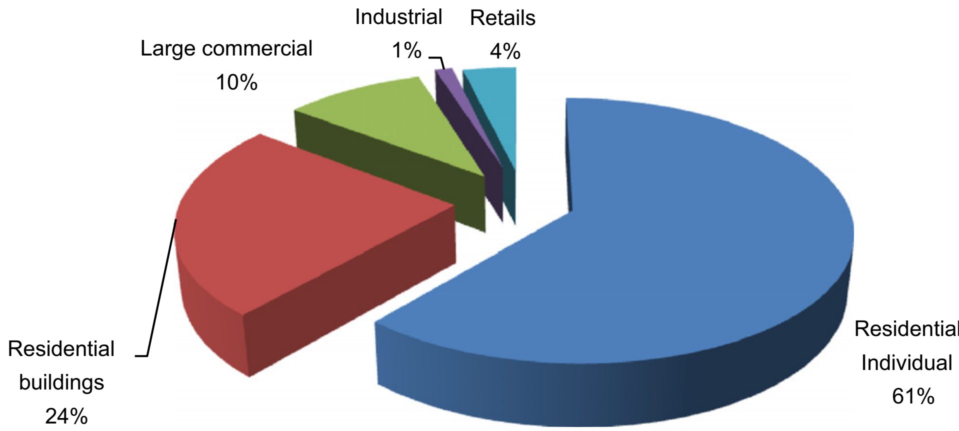

Fig. 7. Breakdown of the Lebanese solar thermal applications [37].

Table 9
Installed large solar water heater units [34].

Name of beneficiary	Capacity/size (liters)	Qadaa
Installed		
Saida gov. hospital	6000	Saida
Jezzine gov. hospital	3000	Jezzine
Abdullah El-Rassi hospital	4000	Tripoli
Hermel hospital	4000	Hermel
Tripoli gov. hospital	12,000	Tripoli
Keserwen gov. hospital	6000	Keserwen
Sibleen gov. hospital	6000	Chouf
Ehden gov. hospital	500	Bcherri
Sir el Donieh gov. hospital	2000	Donieh
Baalbeck Army Institute	24,000	Baalbeck
Ongoing		
Roumieh Prison	32,000	Mount Lebanon
Qartaba public hospital	500	Mount Lebanon
Bscharreh public hospital	1000	Bscharreh
DahrEl Beshiq public hospital	6000	Metn
Bent Jbeil public hospital	6000	Bent Jbeil
Planned		
Military academy	12,000	Mount Lebanon

systems cannot currently compete with the existing oil-based method to produce electricity in Lebanon.

6.3.3. *Solar thermal power plants*

Lebanon does not have any solar thermal power plants using concentrating collectors. Such an initiative is rendered unsuitable mainly due to limited appropriate areas for this type of power plants, which needs about 2–6 ha per MWh. Furthermore, thermal and photovoltaic systems market in Lebanon has to be standardized and normalized at a national level and diffused by the relevant national standardization body. Effectively, the Industrial Research Institute has begun a certification program for solar water heaters.

6.4. *Biomass (bioenergy)*

Forest in Lebanon does not cover more than 3.5% of the total land area which is equivalent to 350 km^2. However, Lebanon is considered to have important sources of biomass and for the most part represented by the municipal solid waste. This waste may be divided into two categories residential waste estimated at about 4200 t a day, and non-residential waste mainly commercial, industrial and estimated at about 600 t a day [36]. These wastes

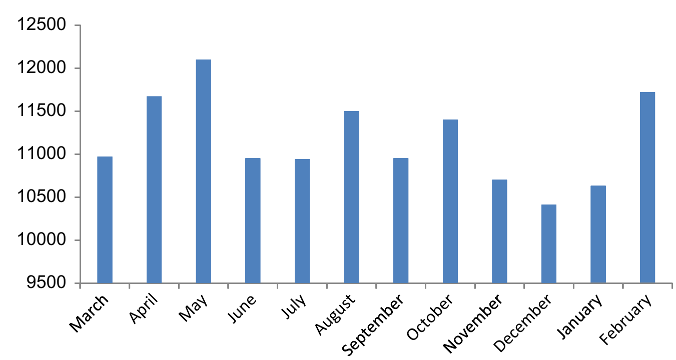

Fig. 8. Thermal solar energy produced (kWh th) in 2010–2011 by the large SWH installed.

can be recycled, reused, transformed, burned or converted into electricity and heat while the remains could be consumed as natural fertilizers. Several studies were carried out on Lebanese solid waste landfills (Bourj Hammoud, Quarantinah, Naameh, Normandie) and have shown high gas storage potential. If we take the case of Bourj Hammoud landfill, its gas storage potential is about 170 m^3 for the period spanning from 2001 to 2015 with a methane percentage of 45–55% and thus a possibility of generating 850 GWh during the cited period. An averaged thermal energy based on various components of solid waste is depicted in Table 11.

Lebanon does not benefit from these resources although they could provide around 30% of the country's electricity needs. In fact, for a country like Lebanon, it is better to benefit from such wastes in recycling material. It is estimated that biogas energy and farm waste cover 2.4% of the total energy consumption of the country, which is equivalent to 48,000 TOE (tone of oil equivalent, 1 TOE = 42 GJ), the amount used for space heating [38].

7. Renewable energy barriers and solutions

Although the efforts that have started by the support of NGO financed projects though which a center for energy conservation was created (Lebanese Center for Energy Conservation) that promotes energy efficiency and renewable energy and the establishment of the national financing mechanism (National Energy Efficiency and Renewable Energy Account (NEEREA)), the centers still need to be institutionalized within a complete energy conservation law. There are many barriers that prevent the expansion

Table 10
Penetration of S.W.H. in Lebanon, annual radiation 2 MWh/m^2 in a collector with slope 25%.

Year	2005	2010
S.W.H. ($\times$ 1000 m^2)	250	700
Energy saved by the user in MWh (40% efficiency $\times$ 0.6 used)	125,000	350,000

Table 11
Averaged thermal energy based on solid waste in Lebanon [36].

		Year		
		2003	2015	2040
Average daily solid waste	Metric ton	3900	5700	12,000
Average annual solid waste	1000 metric tons	1425	2080	4380
Average annual potential thermal energy	1000 t equivalent to fuel oil or gas oil	317	46	973
Average clean methane gas extracted annually	1000 metric tons	99	154	338
Average annual thermal energy in methane gas	1000 metric tons equivalent to fuel oil or gas oil	120	188	421

Table 12
Planned investments for renewable energy in Lebanon (by type) [27].

Type	Objective	Program cost	Savings	Source of funding
Hydro	40 MW installed capacity by 2015 and 80 MW to be installed later	700 M$	140 GWh/year or 14 M$/year till 2015	Private sector and international loans
Wind	60–100 MW decentralized production by 2014	115–190 M$	120–200 GWh/year or 12–20 M$/year	UNDP/CEDRO, NEEREA, and private sector
Solar thermal	To promote the use of solar water heaters mainly in the residential sector so as to obtain around 30% savings	1.5–3 M$ (financial mechanism for SWH)+$750,000 (SWH)+$80,000 (testing facility)+$50,000 (awareness campaigns)	3.5 MWh/year/unit or 343 $/year/unit in 2011, for 7500 SWH, 26.25 GWh/year or 2.6 M$/year in 2020, for 250,000 SWH, 875 GWh/year 85 M$/year	UNDP, International donors, Central Bank, and GoL
Decentralized power generation by PV and wind applications in the residential and commercial sectors	50–100 MW decentralized power generation by PV by 2015	250–500 M$	131–263 GWh/year or 13–26 M$/year by 2015	NEEREA, CEDRO (wind atlas)
Solar thermal power plants	100–200 MW	Feasibility study: 40,000 USD, private funding is still being negotiated	263–526 GWh/year or 26–52 M$/year by year 2014	UNDP/CEDRO, international donors, and private sector
Biomass, geothermal, and other technologies	15–25 MW	30–50 M$	66–132 GWh/year 6–10 M$/year	UNDP/CEDRO, NEEREA, CDM

of renewable energy technologies in Lebanon and following are some important ones [28,29,33,35]:

1. The lack of reliable data for wind, solar and water resources.
2. The absence of a proper institutional agenda that would clarify the role of each authority in addition to the lack of incentives that would promote the use of renewable energy sources.
3. The high cost of renewable energy technologies in comparison with the existing conventional technologies.
4. The non-existence of local manufacturers and clear norms that would guaranty the quality of renewable energy technologies, not to mention the shortage of well trained technicians.
5. The unawareness of the huge economic and environmental benefits of renewable energy sources by the society.

In order to overcome these barriers a series of suggestions are proposed that form the basis from which the renewable energy market would depart:

a) Adopt a general national real plan for the renewable energy in Lebanon that covers the technical development and the legislative actions that have to be adopted in parallel by the government to organize this sector within a global strategy that respects the principles of sustainable development.
b) From a technical point of view, university-based research energy centers that work on programs funded by the government and/or the private sector have to be established. These centers should encompass the required technical skills and expertise to study and elaborate adequate solutions for the Lebanese renewable energy sector. Furthermore, solutions must be expedited by benefiting from the experiences of the developed countries (France, Germany, Spain, etc.) that have been investing in renewable energy for the past two decades through the adoption of their established technical skills and tailoring them to fit local conditions and resources.
c) Create and develop a national database of different sources of energy, which would form the building bricks of the Lebanese renewable energy sector (Wind Atlas, Solar Atlas, etc.).
d) Although thermal solar energy systems have shown an interesting payback period, manifested in the penetration of solar water heaters is the market. A road map has to be identified for thermal solar energy, including photovoltaic and wind

energies, based on a thorough feasibility studies and cost analysis.

e) From legislative and regulation point of view, authorities have a great role to play in the renewable energy market by creating incentives/encouraging investments in this sector, which can be attained through the adoption of some convenient economic laws. These policies must allow for the implementation of joint projects and innovative financing schemes in collaboration with the banking sector, by the adoption of financing structures through Public Private Partnership (PPP) and Independent Power Producers (IPP).

In this context, below are some points to be considered:

- Gradual transfer of actual governmental subsidies for the conventional thermal power plants to renewable energy projects.
- Exoneration of renewable energy imported systems and components from custom duties.
- Grid connection for renewable energy systems.
- Adoption of a new tariffs structure, especially for buying electricity from particular/private sector according to the renewable energy technology used (PV panels, wind turbines, etc.).

Renewable energy generation must be followed by Optimized Demand side Management (DSM) of the electricity usage by the customer through energy efficient buildings and appliances. However, caution has to be exercised by ensuring that the development of renewable energy sectors must not come at the expense of sustainable development and environmental impacts. Finally, civic society has a great role for the dissemination and implementation of renewable energy use through awareness campaigns (media, NGO, etc.)

8. Economic aspects of renewable energy development in Lebanon

The high cost of renewable energy technologies is still the main barrier for the development and investment in these technologies when compared to the existing conventional ones. A recent study conducted by the Lebanese Center for Energy Conservation [27], and approved by the Lebanese Government in February 2012, specified the target capacities to be attained by the new projects and their relevant investment cost and savings. The planned investments for renewable energy in Lebanon are identified by type (Hydro, wind, solar thermal, biomass, etc.) and are listed in Table 12. These projects are funded by various sources from private and public sectors, international donors, loans, and international NGO programs.

9. Conclusions

In this paper a review of the existing renewable energy sources specifically, those related to hydro, wind, solar, and biomass in Lebanon is presented along with some of their impact on the environment and the role they play in mitigating GHG emissions. Lebanon suffers from a great energy bill that results from the high emissions that are the outcome of the non-efficient conventional methods used in the country. Renewable energy is considered to be a virgin sector in Lebanon and thus is susceptible to major improvements. Barriers that prevent these advances along with their remedies are discussed with thorough recommendations that are intended to form the bases from which the renewable energy sector can proceed.

References

[1] GNSED. Global network on energy and sustainable development: overcoming barriers and unlocking potentials. 〈http://www.gnesd.org〉; 2007.

[2] Avetisyan M, Bayless D, Gnuni T. Optimal expansion of a developing power system under the conditions of market economy and environmental constraints. Energy Economics 2006;28:455–66.

[3] Al-Shaalan AM. Essentials of power system planning in developing countries. Journal of King Saud University—Engineering Sciences 2011;23:27–32.

[4] BP Statistical Review of World Energy. Review of world energy. 〈http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf〉; 2011.

[5] Renewables. Global status report. 〈http://www.ren21.net/Portals/97/documents/GSR/GSR2011_Master18.pdf〉; 2011.

[6] Alnaser WE, Alnaser NW. The status of renewable energy in the GCC countries. Renewable and Sustainable Energy Reviews 2011;15:3074–98.

[7] Al Awaji S. Evaluation of solar energy research and its application in Saudi Arabia—20 years of experience. Renewable and Sustainable Energy Reviews 2001;5(1):59–77.

[8] Alnaser WE, Alnaser NW. Solar and wind energy potential in GCC countries and some related projects. Journal of Renewable and Sustainable Energy 2009;1:022301.

[9] Tsikalakisa A, Tomtsia T, Hatziargyrioua ND, Poullikkasb A, Malamateniosc Ch, Giakoumelosc E, et al. Review of best practices of solar electricity resources applications in selected Middle East and North Africa (MENA) countries. Renewable and Sustainable Energy Reviews 2011;15:2838–49.

[10] Jablonski S, Tarhini M, Touati M, Garcia DG, Alario J. The Mediterranean solar plan: project proposals for renewable energy in the Mediterranean Partner Countries region. Energy Policy 2012. http://dx.doi.org/10.1016/j.enpol.2012.01.052.

[11] Identification Mission for the Mediterranean Solar Plan. FWC Beneficiaries Lot 4—No. 2008/168828. Project funded by the European Union and implemented by Resources and Logistics. 〈http://ec.europa.eu/energy/international/international_cooperation/doc/2010_01_solar_plan_report.pdf〉; 2010.

[12] EIB. Study on the financing of renewable energy investment in the southern and eastern Mediterranean region. Luxembourg: European Investment Bank (EIB). 〈http://www.eib.org/attachments/country/study_msp_en.pdf〉; 2010.

[13] Khalil A, Mubarak A, Kaseb S. Road map for renewable energy research and development in Egypt. Journal of Advanced Research 2010;1:29–38.

[14] Ibrahim A. Renewable energy sources in the Egyptian electricity market: a review. Renewable and Sustainable Energy Reviews 2012;16:216–30.

[15] El-Shimy M. Viability analysis of PV power plants in Egypt. Renewable Energy 2009;34:2187–96.

[16] Shaltout M. Egyptian solar radiation atlas. Cairo: New and Renewable Energy Authority (NREA)/U.S. Agency for International Development, IDEA; 1991.

[17] Ahmed AS. Potential wind power generation in South Egypt. Renewable and Sustainable Energy Reviews 2012;16:1528–36.

[18] Elsobki M, Wooders P, Sherif Y. Clean energy investment in developing countries. In: Wind power in Egypt. Winnipeg, Manitoba, Canada: International Institute for Sustainable Development; 2009.

[19] Mortensen NG, Said US, Badger J. Wind atlas for Egypt. In: Measurements and modelling 1991–2005. Cairo/Roskilde: NREA and Egyptian Meteorological Authority/Risø National Laboratory; 2005.

[20] Collelo T, editor. Lebanon: a country study. Washington: GPO for the Library of Congress; 1987. 〈http://www.countrystudies.us/lebanon/29.htm〉.

[21] World Climate Temperature Information. What is the climate, average temperature/weather in Lebanon? 〈http://www.climatemp.info/lebanon/〉; 2011.

[22] Economics, Business, and the Environment—GDP. GDP per capita, current US dollars. Earth trends, economics, business, and the environment: variable. 〈http://earthtrends.wri.org/text/economics-business/variable-638.html〉; 2010.

[23] International Monetary Fund. Lebanese monetary report. 〈http://www.imf.org/external/country/lbn/index.htm?type=9998〉; 2009.

[24] Chedid R, Chaaban F. Renewable energy development in Arab countries: a regional perspective. Journal of Applied Energy 2003;74(1–2):211–20.

[25] Policy Paper for the Electricity Sector. Ministry of energy and water; June 2010.

[26] El-Fadel M, Massoud M, Semerjian L. Energy related GHG emissions: assessment of emission factor uncertainty. World Resource Review 2001;13(1):61–73.

[27] Lebanese National Energy Efficiency Action Plan. LCEC, Ministry of energy and water; February 2012.

[28] Houghton RA. Carbon flux to the atmosphere from land-use changes 1850–2000. Massachusetts, USA: The Woods Hole Research Center; 2009. 〈http://cdiac.ornl.gov/trends/landuse/houghton/houghton.html〉.

[29] Chaaban F, Kaysi I, Chedid R. Contribution of transport to GHG emissions: case study of Lebanon. World Resources Review 2000;12(2):280–97.

[30] Ghaddar N, Mezher T. Modeling of current and future energy intensity and greenhouse gas emissions of the Lebanese industrial sector: assessment of mitigation options. Applied Energy 1999;63(1):53–74.

[31] Chedid R, Chaaban F, Salameh S. Policy analysis of greenhouse gas emissions: the case of the Lebanese electricity sector. Energy Conversion and Management 2000;42(3):373–92.

[32] El-Fadel M, Chedid R, Zeinati M, Hmaidan W. Mitigating energy-related GHG emissions through renewable energy. Renewable Energy Journal 2003;28:1257–76.

[33] Elkhoury M, Nakad Z, Shatila S. Assessment of wind power for electricity generation in Lebanon. Energy Sources, Part A 2010;32:1236–47.
[34] Hassan H. CEDRO's commercial/institutional solar hot water applications: a rapid techno-economic assessment. United Nations Development Program (UNDP). Lebanon Recovery Fund by means of a grant from Government of Spain; 2011.
[35] Lebanese First National Communication Report. Technical annex to Lebanese first national report. 〈http://www.moe.gov.lb/ClimateChange/p1_greenhouse_gases_inventory.html〉; 2002.
[36] Abisaid C. Development and promotion of renewable energies and energy efficiency in Lebanon. isbn:978-9953-0-1222-3; 2008.
[37] Lebanese Solar Energy Society (LSES). Solar thermal systems survey for the Lebanese market; 2006.
[38] World Bank Data. The world at a glance: by country. 〈http://data.worldbank.org/〉; 2009.